29 MAR 2000

AFRL-SR-BL-TR-00-

0083

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE Scanning Laser Vibrometer for MEMS Control Devices	5. FUNDING NUMBERS F49620-98-1-0259
6. AUTHOR(S) William S. Saric	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER

Arizona State University
Mechanical & Aerospace Engineering
Box 876106
Tempe, AZ. 85287-6106

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

Air Force Office of Scientific
Research/NA
801 N.Randolph St.
Arlington, VA. 22203-1977

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 Words)*

This grant purchased a Scanning Laser-Doppler Vibrometer which was used for the remote measurement of the dynamic displacement of MEMS actuators. The vibrometer is capable of measuring minimum displacements of 0.25 μm/s/√Hz at a standoff distance of 2 m. The sample area can be made as small as 200 μm diameter and the frequency response is up to 20 kHz. The device is capable of either continuous or discrete scanning. Besides the displacement information, modal shapes can be obtained for more complicated structures. Digital and computer-graphic output is possible. Details of the equipment are given in the Appendix. The primary use is part of an existing research program that addresses flow control using quasi-static and dynamic roughness elements within a swept-wing boundary layer. The roughness actuators are spanwise distributed near the attachment line and it is important to measure the roughness height under the actual flow conditions. This equipment is also used in three other AFOSR supported research activities as well as in an undergraduate laboratory and a student project.

14. SUBJECT TERMS vibration measurement; laser doppler; dynamic measurements	15. NUMBER OF PAGES 7
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
		unclassified	UL

Final Technical Report on
AFOSR/NA Grant F49620-98-1-0259

Scanning Laser Vibrometer for MEMS Control Devices

1 January 1998 to 28 February 1999

To

Steven H. Walker
AFOSR/NA
801 N. Randolph St.
Arlington, VA 22203-1977

By

William S. Saric
Professor

Mechanical and Aerospace Engineering
Arizona State University
Box 87-6106
Tempe, AZ. 85287-6106

March 2000

Janice D. Bennett, Director
Office of Research Creative Activity
(480) 965-8239

This grant purchased a Scanning Laser-Doppler Vibrometer which was used for the remote measurement of the dynamic displacement of MEMS actuators. The vibrometer is capable of measuring minimum displacements of 0.25 μm/s/√Hz at a standoff distance of 2 m. The sample area can be made as small as 200 μm diameter and the frequency response is up to 20 kHz. The device is capable of either continuous or discrete scanning. Besides the displacement information, modal shapes can be obtained for more complicated structures. Digital and computer-graphic output is possible. Details of the equipment are given in the Appendix.

Primary Use of the Equipment

Flow Control Experiments. The primary use of the vibrometer was part of an existing research program that addresses flow control using quasi-static and dynamic roughness elements within a swept-wing boundary layer. This research work is supported by AFOSR contract *F49620-97-1-0520: Control of transition in swept-wing boundary layers using MEMS devices as distributed roughness*. The roughness actuators were spanwise distributed with spacing on the order of 4-8 mm and it was important to measure the roughness height under the actual flow conditions. These elements are micro-bubbles typically 6–50 μm high and 2–4 mm in diameter and are placed near the attachment line of the swept airfoil where the boundary-layer thickness is of the order of 600 μm. Typically these actuators are bench tested and it is not always known how they respond to the flow field. In fact, we are not surprised that the deformation and response is not nearly the same. In order to properly model the receptivity mechanisms of the actuators, the actual displacement must be known. The vibrometer was successfully used as intended and is a fundamental part of the research effort.

Secondary Uses of the Equipment

Receptivity Experiments. The vibrometer was used to map the amplitudes and mode shapes of leading-edge vibration under the influence of pulsed sound waves. This research work is supported by AFOSR Contract *F49620-00-0075: Pulsed-sound measurements of the influence of high-amplitude noise on boundary-layer transition to turbulence*. One of the nagging questions regarding leading-edge receptivity is the extent of the leading-edge vibration which can, by itself, generate unstable waves. The vibrometer revealed that leading edge vibrations are on the order of tens of nanometers and hence not a problem for the experiment.

Micro-Aerial Vehicle Research. The vibrometer was used to map out the natural frequencies of the M-Dot microturbine. The M-Dot turbine is a candidate propulsion system for the micro air vehicle project which is supported by AFOSR Contract *F49620-99-1-0089: Aerodynamic studies of micro-air vehicles*. The rotational speed of the turbine is 300,000 rpm and we demonstrated that one of the principal natural frequencies is also 300,000 rpm (5 kHz).

Educational Use of the Equipment

Student Project. Under the direction of Dr. Valana Wells, one of her students has been using the laser vibrometer to characterize the natural modes and frequencies of four violas. The viola is a mid-sized bowed, stringed instrument of the violin family. Its strings are tuned to play in a frequency range from 130 Hz to about 1kHz (depending on the skill of the player), with the most important range between about 195 and 300 Hz. However, the instrument is physically sized to play higher frequencies. Even the largest of modern violas has an optimum frequency band between 300 and 400 Hz. The current research is focused on the study of an alternative viola design that effectively enlarges the instrument while maintaining (and even improving) its playability. Two of the instruments tested so far are of the traditional style and two are the new "Pellegrina" design. The most striking result examined so far is the similarity of the normal mode shapes between the conventional, symmetric viola and the new, asymmetric Pellegrina. It does not appear that the modal frequencies of the Pellegrina are shifted down as much as anticipated. However, since the specific modes (air and structural) have not yet been identified, no conclusion has yet been drawn on this issue. Both top and back plates of each viola were scanned with grids of between 500 and 750 points per plate. The instruments were excited by striking the bridge with a small hand-held modal hammer. Each measurement was averaged over ten strikes. Correlation was generally excellent, with correlation coefficients of 0.9 and above over most of the surface.

Undergraduate Laboratory. The vibrometer has been used in the *MAE 415 Vibrations* under the direction of Dr. Marc Mignolet. This is a four-credit-hour class that includes work in the vibration laboratory. Typical student experiments include the measurement and display of modes shapes for continuous systems.

APPENDIX: EQUIPMENT AND COST LIST

AFOSR/DURIP AWARD $95,000.00
ASU COST SHARE ESTIMATED $51,375.00
TOTAL ORIGINAL PROPOSED BUDGET $146,375.00

SCANNING LASER VIBROMETER EQUIPMENT PURCHASE LIST

Vendor/Manufacturer
Polytec PI
3152 Redhill Avenue, Suite 110
Costa Mesa, CA 92626
Contact person: Mario Pineda

(1)	PSV-200-1	Turnkey high performance scanning vibrometer, consisting of:
(1)	OFV-303	Laser sensor head with remote focus, mounted in OFV-055-D scanning head. This head uses the OFV-MR lenses for use with small parts.
(1)	OFV-3001-S	Vibrometer controller including power supplies for bean scanners inside OFV-055-D, 6 velocity ranges: 1,5,10,25,125 and 1,000 mm/s/V, 2 channel analog anti-aliasing filters, 2-channel 8^{th} order low-pass filer boards, cut-off frequencies 400 Hz to 100KHz, 28 settings
(1)	OFV-055-D	High performance scanning head with 24x digital zoom lens, video camera, includes scanning mirrors, motors, drive electronics baseplate and housing. Wired for remote focus control of laser beam. Live CCD video camera with auto/manual focus & zoom.
(1)	PSV-Z-050	Video control panel for zoom and manual/auto focus control of OFV-055-D video system.
(1)	PSV-Z-031	Data management system: Includes host computer/processor, Windows NT-based PSV-200 software, network adapter, video board for interactive live video fully integrated into software for scan set-up, data presentation overlay, data interrogation & set-up, data presentation overlay, data interrogation * diagnosis, 2 channel FFT digital antialiasing filters, dual-diagnosis, 2 channel FFT digital antialiasing filters, dual-channel D/A converter for scanner control, IEEE interface for OFV-30001-S Version F Controller, dual-channel D/A converter for scanner control, dual-channel ADB with 200 KHz, max, bandwidth, DSP for computation of the FFT, 3,200 FFT lines (2 channel), entire spectrum stored at every scanned point, complex spectral analysis provided according to well established industrial standards with H_1, H_2 and coherence functions displayed in analyzer mode (for single points) and area scanning mode for up

to 512 x 512 points, measurements can be made with various excitation types (including random), user selectable windowing functions and number of averages, results displayed in colors graphs, isolines and 3-D wire mesh, software for animation of operating deflection shapes, results scaled in acceleration, displacement, velocity, degrees & force, Ethernet data link TCP/ID protocol software with HFS-client or PC. Network software will be configured to the requirements of the customer. 10m interconnecting cable scan head to console

BASE PRICE $121,710.00

(1) OFV-055-C Demo, close-up attachment. Superimposes video and laser axes. For measuring small parts. Includes set up close up lenses.

PRICE $3,040.00

(1) PSV-Z-065 Software for controlling HP-33120A wave function generator by PSV-200-3

PRICE $850.00

(1) PSV-Z-068 High resolution FFT. Extension of maximum number of FFT lines to 6,400 for two channel, including A/D board memory extension.

PRICE (no charge)

(1) PSV-Z-067 Fast scan, for quick preview of the vibration pattern. RMS can be displayed as well as magnitude and phase (if a reference signal is used). Magnitude with phase can be animated. Laser stops scanning for each measurement ensuring optimum data quality and spatial accuracy.

PRICE $840.00

(1) PSV-Z-069 Desk-top version of PSV-200 software for display, manipulation and hard copy of PSV-200 data by you or one of your colleagues. Each copy requires the following minimum platform:
Pentium Processor
16 MB of RAM, CD-ROM
Color display 256 colors 800x600 pixels resolution
Windows NT 4.0 operating system with drivers for display

PRICE $3,250.00

(1) PSV-OTT On-site training for the PSV-200-1. Travel expenses are included.

PRICE $2,500.00

(1) Freight Charges

PRICE $150.00

TOTAL AMOUNT TO POLYTECH PI FOR PURCHASE $132,340.00

ADDITIONAL PURCHASES AS FOLLOWS:
Vendor/Manufacturer
Gateway 2000, Inc
P.O. Box 2000
North Sioux City, SD. 57049

(1) Intel 400 MHz Pentium II Xeon processor with 512k full speed cache (dual processor upgradeable). Memory: 256 MB (2-128 MB Modules) 100 MHz ECC SDRAM expandable to 1024 MB (2GB with 512 MB modules when available). Monitor: VX1100 21inch color monitor (19.7 inch viewable area). Graphics Accelerator: Accel Graphics Permedia 2 8MG SCGRAM. Hard Drive: 9 GB SCSI 7,200 rpm drive: Floppy Drive: 3.5 inch 1.44 MB diskette drive. DC-ROM 13X min./32X max. SCSI CD-ROM. Multimedia package: Sound Blaser Audio PCI 64V & Boston Acoustic Media Theater Speakers. Case: E-5250 Full Tower Case. Network Card: 3COM PCI 10/100 twisted pair w/WOL. IOMEGA Drive: IOMEGA internal ZIP drive w/2 zip disks): Keyboard: 104+ keyboard. Mouse: MS Intellimouse & mouse pad. LANDesk Software: Intel LANDesk Client Manager Software v 3.1. Operating system: Windows NT 4.0. Service Program: Gateway Gold TM Service and Support. McAfee Anti virus Software

PRICE $5808.00

Vendor/Manufacturer
Micro Warehouse
47 Water St
Norwalk, CT. 06854-9958
Contact: Craig Scig

(1)	ME7552	HP Surestore DC-R 25 pk, 74 min, 650 MB
(1)	ME7550	CD-RW HP Surestore 3 pk, 74 min, 650 MB
(1)	SC5756	Premier 5.0
(1)	DR8471	Tape D HP Colorado 8GB Ext
(1)	DR7995	CD-RW HP Surestore 7200 E 2x2x6
(1)		Shipping Charges

PRICE $1,205.45

Vendor/Manufacturer
DDI (Digital dimensions)
3224 South Fair Lane
Tempe, AZ. 85282

(1) SolidWorks 98 (Windows NT or Window 95) Software
PRICE $300.00
Vendor/Manufacturer
Hewlett Packard
P.O. Box 101149
Atlanta, GA. 30392

(1) 33120A 15 MHz function/arb waveform generator w/std. Functions and 12-bit, 40 MS a/s, 16k-deep arb. AM. FM. FSK and burst are standard, as are linear and log sweep. HP-IB and RS-232 interfaces built in.

PRICE $1436.00

Vendor/Manufacturer
ASU Stores

(1) Hewlett Packard Color LaserJet 5M Printer

PRICE $4527.23

TOTAL EXPENDITURES FOR DURIP GRANT INCLUDING COST SHARING $145,616.68